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## LNG Changes In The Context Of The Expanding Market Of Natural Gas

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### Abstract

*In the context of the continually expanding demand of natural gas worldwide, the LNG industry is undergoing significant changes in its trade structure and shipping characteristics. The growth in LNG trade will continue and with it the growth of the LNG shipping industry. Departing from the rigid structure of the traditional LNG trade, the introduction of trade flexibility through development of short-term contracts and spot trading is altering the picture in LNG shipping.*

*In the current work, the evolution and future of LNG trade as a share of the natural gas trade is presented and analysed, with respect to worldwide and regional (mainly European) supply and demand and its competition with other current (pipeline) and emerging natural gas transportation alternatives. Changes in the structure of the LNG trade, in LNG chain economics and LNG fleet characteristics are detected, correlated and assessed. All efforts towards improving the competitiveness of the LNG industry must take into account the above-mentioned changes and, to this extent, it is revealed that the shipping link of the LNG chain presents adequate margins for technological advances. In this respect, areas of priority and measures for promoting the economics, reliability and safety of the LNG tankers are proposed.*

**Keywords:** LNG trade, LNG shipping, LNG market

**JEL CODES:** F14, F18

### Introduction

Over the last forty years, natural gas has gradually attained a larger share of the world's primary energy consumption, starting with 16.4% in 1965 and reaching 24.3% at the end of 2002, with 2.3 billion tons of equivalent oil (toe). Natural gas, in view of its higher calorific value, better fuel efficiency and eco-friendly nature, is gaining an increasing consuming acceptance compared to oil and coal, which are currently consumed at nearly 40% and 25%, respectively, with the balance being shared by nuclear source, hydro-energy, etc. For Europe<sup>3</sup>, the corresponding increase of natural gas consumption was almost tenfold, from 2.3% in 1965

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<sup>3</sup> Europe or European stands for EU-15.

to around 24% in 2002 with 350 million toe. These trends clearly indicate that natural gas will constitute in the future an even larger percentage of the international and European fuel mix. Indeed, in the next thirty years, worldwide and European natural gas consumption is predicted to have the fastest growth of all energy sources with an average increase of 2.4% and 1.7% per annum, respectively (BP, 2003; EU, 2003).

Currently, worldwide proven<sup>4</sup> reserves of natural gas are estimated at almost 160 trillion cubic meters (cu.m.), which is almost double to the estimated level at the beginning of the 80s (85.9 trillion cu.m. in 1982) and four times higher to that at the beginning of the 70s (39.5 trillion cu.m. in 1970). At the turn of the century, the gas-to-oil ratio of proven reserves became higher than 1.0, whereas in 1970 was nearly 0.5. Europe and Eurasia (mainly Russia) are the current leaders of proven natural gas reserves with a total capacity of just over 60 trillion cu.m., whereas the Middle East (mainly Iran and Qatar) is a close second with 56 trillion cu.m. and Pacific Asia (mainly Indonesia, Malaysia and Australia) and Africa (mainly Algeria and Nigeria) distant third and fourth with 12.6 and 11.8 trillion cu.m., respectively. Furthermore, world's ratio of proven natural gas reserves-to-production (R/P ratio) is currently around 60 years, whereas the oil R/P ratio is nearly 40. Therefore, at the present levels of production, proven natural gas reserves have a longer lifespan than that of oil. It is also important to note that the Middle East has an almost fourfold R/P ratio to the world average. Over the last thirty years, new technologies have rendered stranded natural gas reserves more exploitable, so the ratio of stranded to proven reserves has decreased from 6:1 in the beginning of the 70s to the current ratio of about 3:1. However, natural gas proven reserves are still concentrated in a small number of countries (80% of gas in twelve countries), which are also generally remote from the main countries of demand. In this background of gas-rich and producing regions, the Atlantic basin (mainly Europe) and Asia (mainly Japan) constitute the two main consuming regions. To this extent, it is important to note that the import dependency of Europe in natural gas is predicted to rise from the current level of 44% to 80% by the year 2030 (BP, 2003; EIA, 2002; Chabreli, 2002).

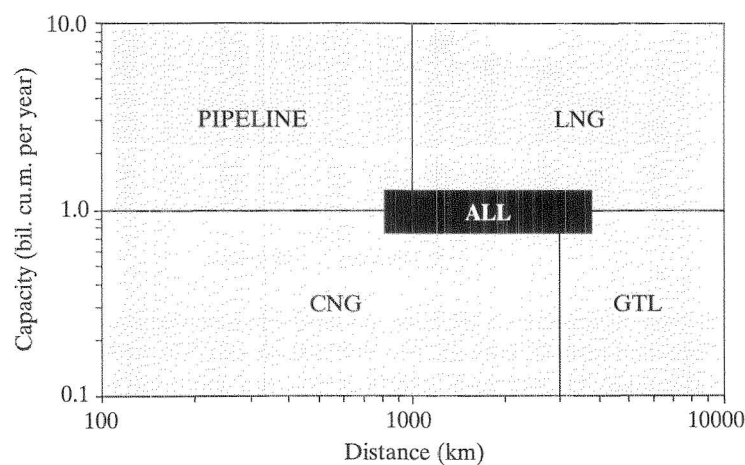
### **1.1 Natural gas transportation technologies**

From the producing to consuming regions, natural gas is mainly transported through pipelines as gas or by specially designed tankers in a physically liquefied form through cooling. The term "liquefied natural gas" or LNG is used to describe a variety of liquefied gas mixtures composed primarily of methane and small quantities of heavier hydrocarbons and nitrogen. At the point of distribution, LNG typically contains at least 90 percent methane. The choice between LNG or pipeline gas depends on a variety of geopolitical, technical and commercial factors (EC, 2001; Avidan, 1997). In general, pipelines are preferred for short distances and

<sup>4</sup> Proven reserves: Generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions, as opposed to stranded reserves.

LNG tankers for long distances, although processing capacities are also important (Gudmundsson et al, 2001). However, even for shorter distances, geopolitical issues such as “rights of way” and political stability (security), and technical factors affecting pipeline route, such as mudslides and earthquakes might make LNG more suitable. Both LNG and pipeline gas, however, require large gas production volumes in order to be economically feasible (Figure 1).

**Figure 1**  
*Capacity Vs Distance for various natural gas transportation technologies*



Compressed Natural Gas (CNG) and Gas-to-Liquids (GTL) are emerging technologies with a potential to fill the gap between pipeline transport and LNG, particularly at low processing capacities. The former relies on physical liquefaction through gas compression and the latter is based upon the chemical conversion of the gas in a liquid product, such as methanol or synthetic hydrocarbons (Cayrade, 2003; DnV, 2003; Jensen, 2002; Wagner et al, 2002; Gudmundsson, 2001; Quinn, 2001). However, in view of the increasing natural gas demand worldwide and until these alternative transportation technologies of natural gas become more cost effective, it may reliably argued that LNG shipping by virtue of its sustained excellent safety record and improved economics (reduced LNG chain costs and extended vessel lives) is not only here to stay, but to expand even further. (IELE, 2003a; IELE 2003b).

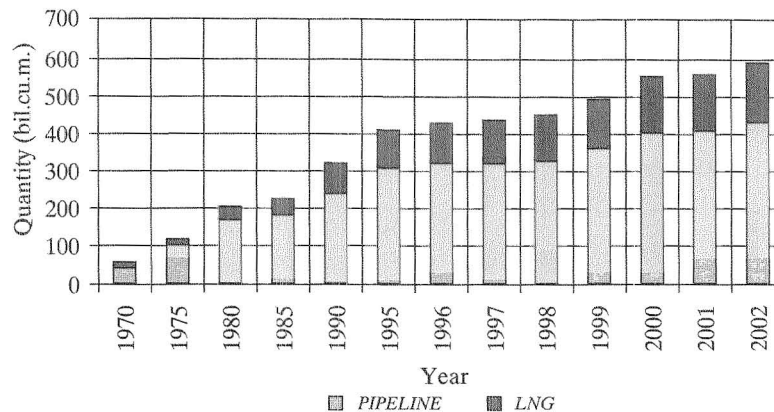
In the context of increasing consumption of natural gas worldwide and regionally, the current work concentrates on the presentation and analysis of the determinants of emerging and future changes in the LNG industry and shipping.

## 2. Global and European LNG Market

Of the natural gas production currently marketed worldwide, about 28% is internationally traded and one-fifth of this trade is in LNG form. Therefore, nearly

6% of the world's natural gas production, i.e. about 135 million toe or 150 billion cu.m., is transported by sea.

**Figure 2**  
*Worldwide growth of LNG and pipeline natural gas*

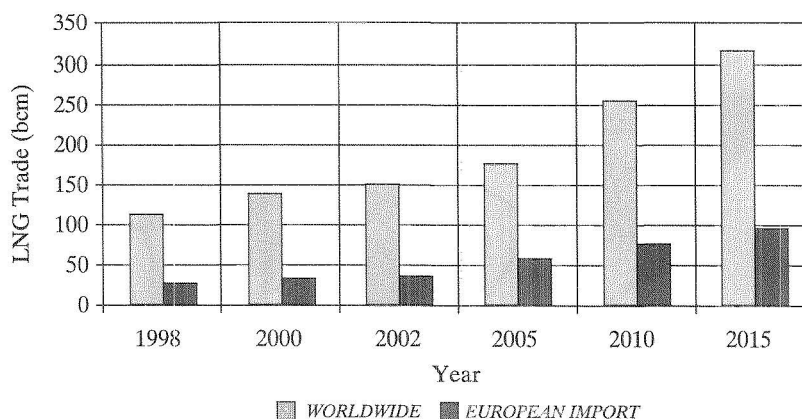


Over the last 30 years or so, pipeline gas has been losing ground to the transport in its liquefied form (Figure 2). The global share of LNG trade in comparison to piped natural gas has increased significantly, from about 6% in 1970 to about 10% in 1975 and nearly 30% today (LNG One World, 2003; Watts, 2003; Davies, 2001). Under the pressure of increasing demand for natural gas, it was necessary to bring into the market more remote reserves, which were stranded by distance. In response, recent technological developments have improved LNG project economics throughout the LNG chain, from exploration to consumption, and improved the share of LNG in the total international trade (Chabrelie, 2002).

In a modest prediction scenario (OSC, 2003; Cook, 2003), the annual worldwide LNG trade is expected to increase from the level of around 150 billion cu.m. in 2002 to over 175 billion cu.m. in 2005, 256 billion cu.m. in 2010 and 318 billion cu.m. in 2015 (Figure 3). After doubling in volume since 1990, therefore, the world LNG trade is predicted to increase overall by over 75% in the period to 2010 and by 118% in the period to 2015, the highest increase in LNG market share expected for the Far East, Europe and USA. Similarly, with reference to Europe (CIEP, 2003), in view of the future increase of European natural gas demand, LNG imports to Europe are expected to increase from just over 36 billion cu.m. in 2002 to around 58 billion cu.m. by 2005, 75 billion cu.m. by 2010 and 95 billion cu.m. by 2015, representing a growth by 112% in the period to 2010 and by 162% in the period to 2015, despite the anticipated increase of Russian pipeline gas exports to Europe (Figure 3).



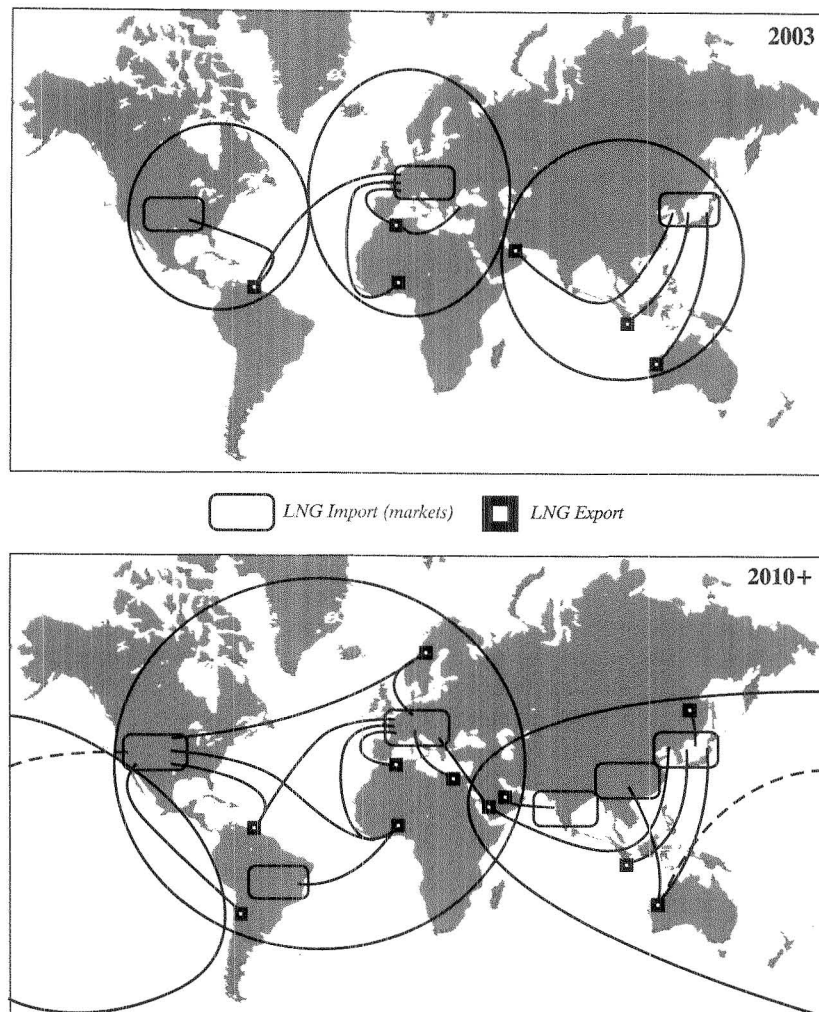
**Figure 3**  
*Growth of World and European LNG trade*



In 2002, the largest LNG importing area was the Far East, where major importers were Japan, with 74.1 billion cu.m., and the Republic of Korea, with 21.8 billion cu.m. Supplies came from Indonesia (31.8 billion cu.m.), Malaysia (20.9 billion cu.m.), Qatar (15 billion cu.m.) and Australia (10.2 billion cu.m.). The share of smaller suppliers from the Gulf is poised to grow and Iran is seeking to supply China, whose 2002 imports increased by 28 per cent, with Saudi Arabia being the largest supplier. The largest share of the 3.6 billion cu.m. of exports from Trinidad went to the United States market, which also took almost 1 billion cu.m. from the Middle East (Qatar and Oman) and 1 billion cu.m. from Nigeria. In Europe, in 2002, LNG importing countries were France, Spain, Italy, Belgium and Greece, with the highest share being held by France (10 billion cu.m.), followed by Spain (5 billion cu.m.) and Italy, and the lowest share of LNG coming into Greece. The main LNG exporting country to Europe was Algeria with 25.5 billion cu.m., followed by Nigeria (6.8 billion cu.m.), Libya and Trinidad, in addition to small supplies from Oman and Qatar (UNCTAD, 2003).

In the long term, the trend of increasing European LNG imports mainly stems from its favourable transportation economics over long-distances and its superiority with respect to supply security, compared to pipeline gas, whereas the offshore pipelines are limited to even shorter distances. In a framework of rising European gas demand, despite the presence of the close-by gas-rich Russia, the above mentioned criteria will generally favour European LNG imports from new and expanded facilities in non-traditional and traditional exporting countries respectively, such as Iran, Libya, Egypt, Oman, Qatar, Angola, Venezuela, Yemen and Namibia and particularly so to countries of south-western Europe (i.e. of the Iberian peninsula), France and the U.K. (CIEP, 2003; Dri-Wefa, 2003).

**Figure 4**  
*Growth of LNG trade through major flows*



The world LNG market traditionally falls within the framework of the main characteristics of the world gas market, i.e. it is a very rigid (long term contracts, Take or Pay clauses, small spot market), regional (technical, economic and security limitations), concentrated reserves, hence cartel threat (similar to OPEC), very recent liberalization, as in Europe through TPA<sup>5</sup> and unbundling requirements

<sup>5</sup> TPA: Third Party Access is the right or opportunity for a third party (shipper) to make use of the transportation or distribution services of a pipeline company to move gas for a set or negotiated charge.

(EU, 1998), and increased immersion into end-use energy (power). It is, however, reliable to predict that under the pressure of emerging market conditions, the LNG industry will respond successfully towards increased diversity of demand in parallel with a steady diversification of supply and it will transform from a regional to global activity, showing increasing overlap and complexity (Figure 4).

#### **4. LNG Trade Structure**

A typical LNG project involves production (onshore or offshore), pre-treatment and liquefaction, shipping, unloading, storage and re-gasification. These are usually coordinated and developed concurrently; thus each activity constitutes a component of the “LNG puzzle”. Although the owners/operators of each component may be different, all the investments made are geared towards delivery of gas to the end user. Accordingly, it makes no sense to develop or invest in any of the aforementioned activities unless a long-term Supply and Purchase Agreement (SPA), is in place. Therefore, it is not surprising that the production capacity and delivery infrastructure has traditionally been almost equal to the total contracted demand (Farmer, 1999). Considering the large investments and high risks involved, none of the potential players in an LNG project will normally invest in a component activity until receipt of formal confirmation indicating that all other players are equally committed contractually. As a result, the sponsors of LNG projects tie the different aspects of the project contractually so as to mitigate risks and enable easier financing. Hence, till almost ten years ago, reference to an international LNG market was an anomaly, because it was actually an accumulation of contractual monopolies (Greenwald, 1994).

More recently, however, the rapidly increasing demand in natural gas<sup>6</sup> and the subsequent cost reduction along all the links of the LNG chain (through the influence of economies of scale and technological development) has increased LNG competitiveness. Hence, whereas traditional LNG businesses required firm, long-term arrangements with volumes, prices and customers fixed for 20 years, LNG suppliers and buyers are taking more flexible approaches. Contract terms have become increasingly flexible, with prices more frequently determined by netback calculations from competitive markets and supply sources more interchangeable. Duration is also shifting with buyers now looking for a variety of durations five (one-two and three-five) years or less to complement established 20-year LNG contracts. Infrastructure is also being built and acquired on more speculative basis. Liquefaction and re-gasification plant expansions are being built with only part of their capacity locked in to long-term, fixed-volume commitments. More specifically, as more companies move to reduce costs by building larger facilities, a buildup of spare, uncommitted export capacity is emerging. Price de-regulation in many countries and other factors have contributed to a fall in the typical size of new individual LNG sales deals. This trend is leading to increased mismatching between sales contract sizes and plant

<sup>6</sup> Furthermore, the increased use of natural gas particularly in the residential and commercial sectors will inevitably lead towards the increase of seasonal variations in demand. LNG will be called upon to fulfill these seasonal demand fluctuations too.

construction size targets. In addition, many LNG tankers on order for delivery are not directly tied to firm contracts. As supply sources spread, spot transactions have risen in number, leading to speculation that the structure of LNG markets is entering a period of transition (Drewry Shipping Consultants, 2003).

The similarities to the early development of spot crude oil markets render evidence to the idea that with time LNG spot trade could become global. The development of a transparent, highly flexible, global spot market for crude oil took less than a decade. It can be reasonably argued that LNG now faces the same kind of structural changes as seen in oil markets in the late 1970s and early 1980s. If an oversupply of LNG develops as it did in crude oil markets in the early 1980s, the potential for LNG markets to follow the path of crude oil seems strong.

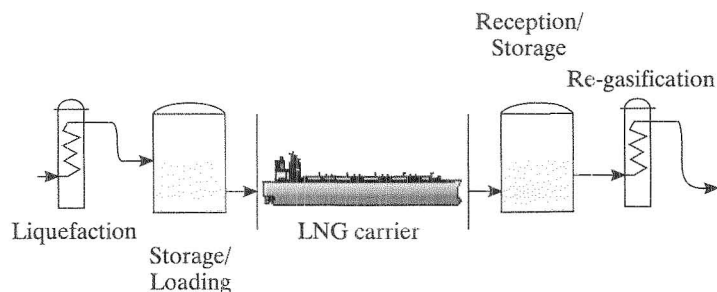
It is inevitable that this change in LNG market structure will eventually influence LNG pricing, since traditionally the price of LNG follows the price of oil only to some extent and varies between regions. This reflected the fact that gas deliveries were and to a great extent still are continuous and regulated by long-term contracts with index clauses. However, new ways of conducting LNG trade introduce spot and short-term transactions, swap agreements are developing and arbitrage between regional markets is taking place to capture the price differentials between markets.

Traditional long-term LNG contracts are gradually being complemented by LNG transactions that are more flexible in timing and location. These transactions are starting to serve as transmitters of price signals between regional gas markets. The rising trend in LNG spot trading (3% and 9% of global LNG trade in 1999 and 2002, respectively) will develop further (OSC, 2003). However, it will not replace long-term contracts entirely, as these contracts will new project investment. In any event, chances are that a global LNG market, such as those for oil or coal, will gradually emerge as LNG trade expands and involves more players.

## 5. LNG Economics

Throughout the LNG chain (Figure 5), namely liquefaction, shipping and re-gasification, an overall cost reduction of almost 30% has been achieved during the last twenty years (IELE, 2003b).

**Figure 5**  
*The LNG chain*



More specifically, over this period liquefaction costs have been lowered by as much as 35%, due to the introduction of competing technologies and economies of scale. The cost of a liquefaction plant, currently sized at an optimum of 4.4-5.5 million tons per annum (mtpa), is of the order of 250 USD/mtpa, while further cost reductions of around 20% are a realistic prospect through technological improvement and multiple unit plants which utilise economies of scale through the sharing of common facilities (CIEP, 2003).

The specialised nature of LNG shipping inevitably limits the number of shipyards in the world with the necessary skills and capacities to build LNG vessels. Most LNG tankers are built in Japan (Mitsubishi H.I., Nagasaki, Mitsui S.B. Chiba and Kawasaki at Sakaide) and Korea (Daewoo H.I. Okpo, Hyundai H.I., and Samsung S.B. Koje), although Spain (Izar Sestao and Izar Puerto Real) has recently successfully delivered LNG tankers. Furthermore, France (Chantiers de l'Atlantique) and Finland (Kvaerner Masa) have the appropriate potential to enter the LNG shipbuilding market, if the passenger market with which are currently involved became weaker and/or the LNG order book becomes heavier. Shipyard expansions in the Far East and increased competition among shipbuilders have lowered (the highly dominant among all merchant ship types) LNG ship costs by 40% from their peak in the beginning of the 90s<sup>7</sup> (UNCTAD, 2003). Emerging demand for larger LNG tankers could produce near-future transportation costs savings in the region of 10-15% (BRS, 2003). In general, as the number of shipyards with the ability to build LNG tankers increases, the competition to secure newbuilding contracts intensifies and prices drop. The need to reduce the price and remain competitive will force shipyards to look for more advances in technology, which will improve production schedules whilst retaining the quality, safety and reliability required by the LNG shipping industry. For Europe, a most recent development (25/06/03) with respect to improving the competitiveness of European shipyards against the unfair practices of their Far-East (namely Korean) counterparts is the European Commission decision to extend the granting of temporary and limited state aid s in the shipbuilding sector (so-called Temporary Defensive Mechanism - TDM) to LNG tankers. Direct aid in support of contracts for the building of LNG tankers was authorised in accordance with the provisions of the European Council Regulation (EC) No 1177/2002, concerning a temporary defensive mechanism to shipbuilding already authorised for containerships and product and chemical tankers. In ship design, new technologies have also contributed to operating cost reductions. Improvements in the efficiency and power density of the steam turbine led to increased cargo carrying capacities and reduced fuel costs, respectively.

Finally, during the last twenty years, economies of scale (in conjunction with TPA) and technological/project improvements have intensified competition among builders of re-gasification plants and lowered their cost by almost 18% (Harmon, 2002).

Despite the observed reductions in LNG costs, the shipping link still accounts for approximately 20-35% of the total delivered cost of LNG, depending on the length of

<sup>7</sup> Newbuilding price for an LNG tanker of 125-135 thousand cu.m. has dropped from 275 million USD in 1991 to 165 million USD in 2002.

the transportation route, i.e. of the distance between the liquefaction plant and the receiving terminal (IELE, 2003b). Shipping costs include fixed costs (such as, initial cost, manning and insurance costs) and variable voyage costs (such as, fuel, boil-off gas and port dues), with fixed costs generally representing almost 70% of the overall shipping costs. The LNG tanker is a key link in the project chain, so both LNG sellers and buyers demand high standards in design, construction, and operation to ensure safety and reliability, all of which are reflected in the high cost of shipping.

The economics of the overall LNG value chain from exploration to re-gasification and storage are currently ranging from 2.0-3.7 USD/MMBTU<sup>8</sup>, according to the following link breakdown (IELE, 2003b):

Exploration & Production:	0.5-1.0 USD/MMBTU
Liquefaction:	0.8-1.2 USD/MMBTU
Shipping:	0.4-1.0 USD/MMBTU
Re-gasification & storage:	0.3-0.5 USD/MMBTU

Traditionally, the import price of LNG has been oil-indexed to some extent, but signs of price decoupling are emerging. However, crude oil and LNG import prices are currently converging to around 4.5 USD/MMBTU and spot market pricing of LNG is occasionally becoming competitive (LNG One World, 2003).

## 6. LNG Fleet Characteristics<sup>9</sup>

The atmospheric liquefaction of natural gas at a temperature of  $-161^{\circ}\text{C}$  has made it possible to transport the gas in a highly "condensed" volume (about 600 times smaller) to distant destinations through sea in appropriately designed tankers. In January 1959, the world's first LNG tanker, the Methane Pioneer (a converted World War II Liberty freighter) carried liquefied natural gas from Lake Charles, Louisiana, to Canvey Island, United Kingdom. This voyage demonstrated that large quantities of liquefied natural gas could be transported safely across the ocean. The Methane Pioneer subsequently carried seven additional LNG cargoes to Canvey Island. In mid-60s 1964, the British Gas Council began importing liquefied natural gas from Algeria, making the United Kingdom the world's first LNG importer and Algeria its first exporter. After the concept was shown to work in the United Kingdom, additional marine LNG liquefaction plants and import terminals were built in both the Atlantic and Pacific regions and through the corresponding expansion of the LNG fleet an increasingly international pattern of LNG trade was established. In 2002, the transport work of the LNG fleet reached 475 trillion cu.m.-miles, compared to approximately 175 trillion cu.m.-miles performed in 1990 (LNG One World, 2003) and involved the LNG transportation of 150 and 75 million cu.m, respectively. Therefore, it becomes evident that during this period LNG

<sup>8</sup> A MMBTU is equal to one (1) million BTU (British Thermal Units). A BTU is the amount of thermal energy required to raise the temperature of one (1) pound of water by one (1) degree Fahrenheit.

<sup>9</sup> The fleet analysis in this section is based on electronic data extracted by Register of Ships, Version 2.11, Lloyd's Register – Fairplay Ltd 2003, London.

hauling distance has increased by almost 36% (from 2.33 to 3.16 million miles), hence reflecting the intensification and/or expansion of LNG trade worldwide.

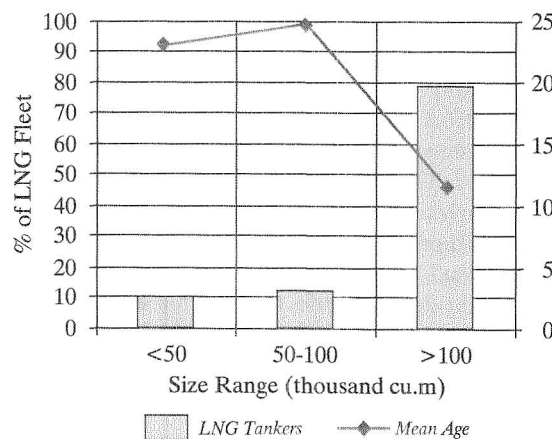
### 6.1 Size and age of LNG fleet

Today, the LNG fleet numbers 146 double-hulled tankers with an overall capacity of 16.85 million cu.m., whilst a further fleet capacity of 8.37 million cu.m. will become available through the pending delivery of 60 ordered tankers up to 2007. In the background of increasing LNG demand worldwide, the expansion of the LNG fleet was expressed through the doubling of the number of tankers during the last decade. Along this trend, it is estimated that by 2010 approximately 250 tankers will be needed to accommodate the forecast LNG trade (Drewry, 2003).

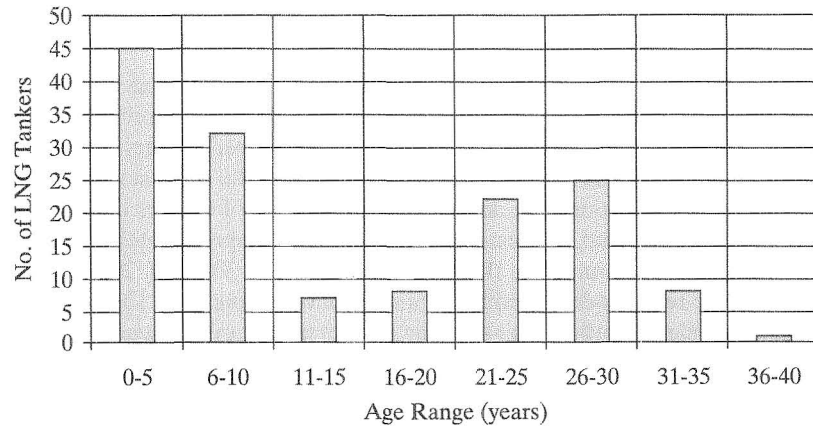
Most of the recently delivered LNG tankers have a capacity of 138,000 cu.m. or more, which is significantly higher than the current mean tanker capacity of 115,411 cu.m. Nearly 80% of the tankers have a carrying capacity higher than 100 thousand cu.m. and a mean age of around 12 years old for this particular size-range (Figure 6). This provides a clear indication of LNG tanker “jumbodising”, in response to the observed increase in LNG demand worldwide.

Today’s LNG fleet sets the “floating bridges” of LNG transport between the currently available 23 liquefaction plants and 45 re-gasification plants worldwide. Most recent considerations point towards the future use of large 200,000 cu.m. tankers for the longer haul planned routes. However, tanker enlargement has to cater for the interface of the vessels with existing LNG and re-gasification terminals, since large-sized tankers are limited by the water and air draft, length and processing capabilities at the loading and unloading ports, respectively.

**Figure 6**  
*Age profile of LNG fleet by group size*



**Figure 7**  
*Age distribution of LNG fleet*



As an alternative to these limiting factors, which inevitably dictate enlargement of existing facilities, new “green-field”<sup>10</sup> and offshore terminals are developed over the next few years. However, these new terminals will present the LNG industry with a whole new range of problems associated with their development.

The mean age of the LNG fleet currently stands at 14.3 years in comparison to 13.9 years ten years ago. Almost 30% of the LNG tankers were built during the last five years and just over 50% of the LNG fleet was delivered during the last decade (Figure 7). This trend in the mean age of the LNG fleet indicates that the significant expansion of the LNG fleet has not led to its renewal, since the replacement of aging (older than 30 years) tankers has been very limited. This is due to the continuous demand for extending the service lives of LNG tankers, in view of the fact that some older ones have already entered into charters that will take them beyond 40 years of operation.

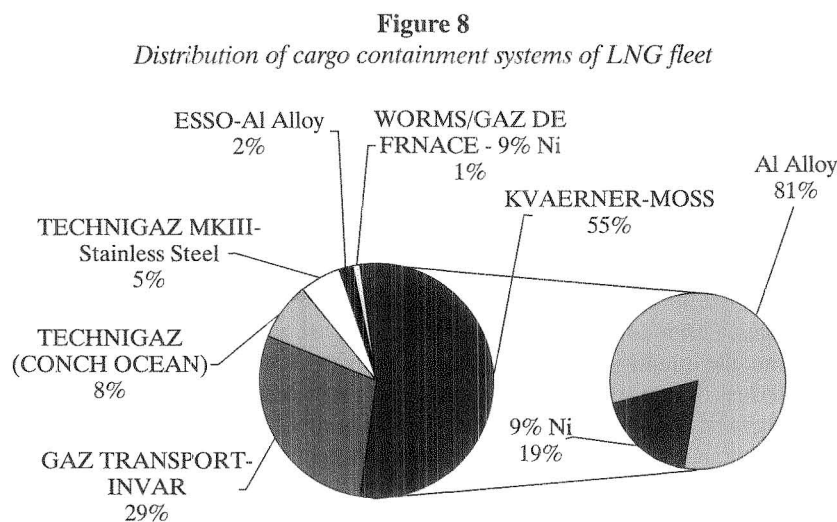
Furthermore, the development of the LNG spot market provides the potential for increased income and some of the recent newbuildings have been ordered on speculation in an effort to take advantage of this market change. When the trading pattern is not known, it is difficult to predict the sea states that the LNG tanker might encounter. This, however, presents the designers with an entirely new problem, particularly as many owners are now specifying a 40 year long (and hence fatigue) life as part of the specification. In an expanding and flexible trading, designers are called upon to extend their prediction with respect to the structural loading a tanker will bear during its life, beyond that which was defined according to known sea states on the various known routes. Therefore, LNG tankers designed and assessed without adequate definition of the trading pattern could suffer, if they encounter conditions more severe than those for which they were designed.

<sup>10</sup> Green-field LNG facility is a new LNG facility constructed on a new site.



## 6.2 LNG containment systems

Various cargo containment systems having various configurations, materials and structures suitable to LNG have been proposed and put into practical use. Three types of cargo containment systems have involved as modern standards: the spherical, the membrane and the prismatic designs (Figure 8).



*Note on main categories of tank design*

MEMBRANE: GAZ TRANSPORT, TECHNIGAZ (CONCH OCEAN), TECHNIGAZ MKIII

SPHERICAL: KVAERNER MOSS

The spherical independent tank type (Kvaerner-Moss) and membrane (Gaz Transport system and Technigaz system) tank type are adopted mainly at present due to their economy and reliability. However, the development of a spot market in LNG trade, together with the emergence of offshore terminals and the extension of tanker hauls introduces the problem of partial cargo loading in the sloshing<sup>11</sup>-vulnerable membrane type tanks. The issue of partial filling of membrane LNG tankers, in combination with the growing preference for this type of cargo containment system, is debated at length by operators, shipyards and classification societies, in search of an optimum response to the operational flexibility dictated by the recent changes in LNG trading. In this context, the building of sloshing-baffles into the tank may be a convenient option, in terms of compromising the merits of membrane tanks with their performance under partial loading conditions.

<sup>11</sup> Sloshing is a free-surface problem of a partially filled liquid tank under oscillation, in this case manifested as the splashing back and forth of the LNG cargo.

### **6.3 LNG Propulsion**

Up to now LNG tankers have been almost exclusively (99%) powered with steam turbines despite their low efficiency and power density (in terms of weight and space requirements), when compared to other available systems, such as (medium-speed) diesel engines or gas turbines. The original reasons for this have been the availability of high power output and the possibility of using low-grade fuels, as well as cargo boil-off-gas. Furthermore, maintenance of the steam turbines is relatively low-cost and infrequent and the systems are considered proven and reliable. However, contrary to the almost stagnant steam turbine development, diesel engines and gas turbines have both demonstrated through time the potential to improve on their inherent capabilities and comply with new shipping demands in general and the emerging requirements of LNG tankers in particular. In terms of the LNG trade changes, short-term contracts and spot cargoes primarily call for a flexible and efficient propulsion plant able to accommodate different operating speeds and alternative operating profiles.

To this extent fuel consumption and hence alternative methods of utilising boil-off-gas, either as fuel or re-liquefied cargo, are under consideration. At the same time, the quantity of boil-off-gas is decreasing in modern LNG tankers (from 0.15% to less than 0.10%), due to improvements in cargo containment insulation technology and design. As a result, the natural boil-off-gas is far from sufficient to fuel the propulsion power needed for the relatively high operating speeds of the LNG tankers. Therefore, forced boil-off-gas or heavy fuel oil is needed to supplement the fuel demand of the steam turbine boilers, both of which increase operating costs. On a laden voyage typically around 50% of the energy requirement comes from heavy fuel, and up to 80% during the ballast voyage.

From the environmental point of view, new criteria of propulsion selection are introduced and alternatives have to be considered. The high fuel consumption of a steam turbine leads directly to high CO<sub>2</sub> emissions. Although NO<sub>x</sub> emissions of traditional LNG tankers are very low (due to the combustion characteristics of boilers), their SO<sub>x</sub> emissions are considerable because of the use of heavy fuel. Finally, for a steam turbine ship called upon to operate with increasing flexibility, the increasing lack of competent (steam) engineers, poor manoeuvring characteristics and limited propulsion redundancy are emerging disadvantages.

In contrast to steam turbine, diesel engine technology has advanced significantly over the years through its extended use in merchant shipping. In particular, however, mechanical or electric propulsion based on dual-fuel diesel engines appears to be a strong option for modern LNG tankers. Similarly, mechanical or electric propulsion based on gas turbines operating on combined cycles may be a candidate for modern LNG tankers, due to their high power density, dual-fuel capabilities and increased cycle efficiencies.

In the developing complexity of LNG shipping, a better propulsion option for tomorrow's LNG tankers is bound to emerge, based upon thorough economic assessments, which take into account all parameters such as improvement in LNG shipping capacity, initial and operating costs, reliability and safety.

#### 6.4 LNG “transport effectiveness”

In order to capture the impact of technology advancements upon the LNG fleet, a measure of LNG tanker “transport effectiveness” is, hereby, defined in terms of LNG carrying capacity, service speed and installed propulsive power, as follows:

$$LTE = \frac{C \times S}{P}$$

where,  $LTE$  = LNG “transport effectiveness” (cu.m.-knots/kW)

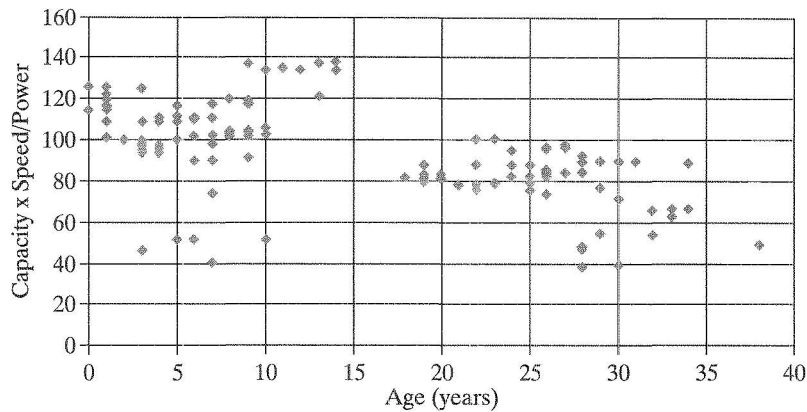
$C$  = liquid gas capacity (cu.m.)

$S$  = service speed (knots)

$P$  = propulsion power (kW)

The technological improvement of LNG tankers is reflected through  $LTE$ , as an expression of transport work performed per unit time against propulsion power requirements. The LNG tankers delivered during the last fifteen years present distinctly higher “transport effectiveness” in comparison to the pre-1985 vessels (Figure 9).

**Figure 9**  
“Transport effectiveness” of LNG fleet



Further analysis reveals that, despite the observed trend of increase in the size of LNG tankers and of negligible service speed changes, the capacity-weighted propulsion power requirements of the newer and larger vessels are lower than those of their older and smaller counterparts. More specifically, the capacity-to-power ratio of the modern LNG tankers (less than 15 years old) is distinctly higher than that of their older counterparts. The improvement of  $LTE$  provides an indication of technological advancements in propulsion engineering and tanker design.

### Conclusions

Following the increasing worldwide demand for natural gas, the nature of LNG trade has changed dramatically in recent years. LNG trade started in 1964 as a small, specialized business (from Algeria) and evolved into a supplementary and often basic trade of energy ranging from Asia (Japan) to Europe to the US. From the 60s through the 80s, contract terms were rigid and long in duration (20-25 years) to cover the risks of building and investing in the expensive links of the LNG chain.

Over the last decade, LNG facilities and transportation costs have fallen dramatically and technology has improved, allowing LNG to spread globally, and prove to be a very competitive alternative to the dominant pipeline. In the new century, the number of LNG operators has grown exponentially, LNG ownership has diversified (industrial to independent) and the rigidity and duration of contracts has loosened considerably, through the emergence and development of short-term contracts and spot market trading.

In this new trading structure, in order to increase further the competitiveness of LNG, major technological challenges are aiming at improving the initial and operating costs of the LNG chain without compromising the reliability and safety of the service. The up to now specialised and somewhat protected environment of LNG shipping has provided adequate margins for the technological improvements necessary to bring LNG shipping in line with the other sectors of the global shipping stage. In particular, for the shipping link emphasis is placed in delivering cheaper, more efficient, reliable and safer tankers. More specifically, in the framework of an expanding LNG trade, initiatives are taken to improve technological LNG shipbuilding competition towards the reduction of initial costs and equip tomorrow's large-sized and long-service LNG tankers with new propulsion plants and cargo containment systems ensuring further improvement in their operating costs, reliability and safety.

### References

- Avidan, A.A (1997), "Lowering the cost of LNG Delivery: impact of technology" 15th World Petroleum Congress, 1997, Beijing.
- BP, 2003. *Statistical Review of World Energy*.
- BRS (2003), "Shipping and Shipbuilding Markets in 2002: The Liquefied Natural Gas Shipping Market in 2002", Barry Rogliano Salles, Paris, 2003.
- Cayrade, P. (2003), "Investments in gas pipelines and LNG Infrastructure: which impact on security of supply", Workshop on Insuring against Disruptions of Energy Supply, Amsterdam, 6th/7th May 2003.
- Chabrelie, M.F. (2002), "Prospects for growth of the gas industry: Trends and challenges", OAPC-IFP Joint Seminar "The Future of Gas", 25-27 June 2002, Rueil Malmaison.
- CIEP (2003), "The Role of LNG in the European Gas Market", Clingendael International Energy Programme, Report No. CIEP 03/2003, Publ. The Clingendael Institute, The Hague.

- Cook, L. (2003), "Liquefied Natural Gas: realising the potential", World Gas Conference, Tokyo, 5th June 2003.
- Dri-Wefa (), "European Gas Supply and Demand: The Outlook to 2025", Publ. DRI-WEFA Energy Services, London.
- Davies, P. (2001), "The New Challenge of Natural Gas", OPEC and the Global Energy Balance: Towards a Sustainable Future, Vienna, 28th September 2001.
- DnV (2003), "Technology Outlook 2003", pp 20-29, ISBN 8251503000.
- Drewry Shipping Consultants (2003), "The Drewry Annual LNG Shipping Market Review and Forecast 2003/04", Report No. R080, Publ. Drewry Shipping Consultants Ltd., 2003.
- EIA, *International Energy Outlook*, 2002.
- EC (2002), *European Council Regulation* (EC) No 1177/2002.
- EC (2001), "Green Paper – Towards a European Strategy for the Security of Energy Supply", European Commission, Com (2000) 769 final, 29 November 2001, Brussels.
- EU (2003), "European energy and transport – Trends to 2030", ISBN 9289444444.
- EU (1998), "Common rules for the internal market on gas", Gas Directive 98/30/EC.
- Farmer, S. (1999), "LNG in the 21st Century", O.G.L.T.R., Vol. 4, 1999.
- Greenwald, G. (1994), "International LNG Projects: Organisation, Implementation, and Contracts", CEPMLP and Petroconsultants Seminar, 22-23 September 1994, St. Andrews.
- Gudmundsson, J.S. and Mork, M. (2001), "Stranded gas to hydrate for storage and transport", International Gas Research Conference, Amsterdam, November 5-8, 2001.
- Gudmundsson, J.S. (2001), "Non-pipeline transport of natural gas", SIG 4032 Naturgass, NTNU, 18 October 2001.
- Harmon, H. (2002), "The Dawn of New Golden Age for LNG", IAEE Houston Meeting, February 2002, Houston.
- IELE (2003a), "LNG Safety and Security", Institute of Energy, Law and Enterprise, University of Houston, October 2003, Houston.
- IELE (2003b), "LNG Economics", Institute of Energy, Law and Enterprise, University of Houston, October 2003, Houston.
- Jensen, T.J. (2002), "LNG and pipeline economics", The Geopolitics of Gas Meeting, Sponsored by Stanford University and Rice University Palo Alto, CA, USA, October 17, 2002.

- LNG One World (2003), <http://www.lngoneworld.com/lngv1.nsf/portal/index.html>.
- OSC (2003), "LNG to 2015: Prospects for Trade and Shipping", Ocean Shipping Consultants Ltd, 2003, Surrey.
- Quinn C. A. (2001), "The Global Regulatory Climate – Fuelling The Growth of a More Flexible LNG Industry", 2nd Annual World LNG Summit, December 2001, Rome.
- UNCTAD (2003), "Review of Maritime Transport".
- Wagner, J.V. and Amott, N. (2002), "Marine transportation of CNG – A viable export alternative", Technical Meeting of Gas Processors Association Europe, 21 February 2002, London.
- Watts, P. (2003), "Building bridges: fulfilling the potential for gas in the 21st century", World Gas Conference, 3 June 2003, Tokyo.